AN OVERVIEW OF CLOSE-RANGE PHOTOGRAMMETRY IN FRANCE

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Résumé

Faire un état de l'art de la photogrammétrie rapprochée en France peut être envisagé sous différentes perspectives : historique, économique, technique, ou selon les métiers. Le présent article prend le parti de faire un court historique, de présenter ensuite les évolutions techniques marquantes pour de nombreux utilisateurs (le passage au numérique, les scanners laser, puis l'ère du tout automatique) et les tendances actuelles de démocratisation de la technique vers de nouveaux métiers, en focalisant particulièrement sur le domaine de la documentation du patrimoine.

Mots clés : Photogrammétrie rapprochée, Méthodes basées image, Lasergrammétrie.

Abstract

There are several approaches which can be adopted to present close-range photogrammetry in France: historical, economic, technical, or by field of application. The paper starts with a short account of the history of close-range photogrammetry. It then presents notable technical progress and its impact on users (the digital era, the laser scanners, and recently the fully automatic tools), and it finally shows the democratization of photogrammetry. The whole paper is mainly focused on cultural heritage applications.

Keywords : *Close-range photogrammetry, image-based methods, laser scanning.*

1. Introduction

Whereas "classical" photogrammetry mostly deals with institutional projects using aerial images, close-range photogrammetry includes all projects where images are taken close to the object of interest, from ground level, from specific devices (rods, kites, drones), or even underwater. Contrary to most aerial projects, close-range photogrammetry projects are most of the time composed of images taken at various scales, with convergent axes, high variations of radiometry, significant occlusions and low cost cameras (Figure 1).

In the present paper, we discuss current applications of close-range photogrammetry in France with a focus on cultural heritage documentation; however, the aim is neither to give an objective nor an exhaustive overview. Indeed, there are several approaches which can be adopted to reach this goal: historical, economic, technical, or by field of application. The paper quickly focuses first on the history of close-range photogrammetry, on notable technical progress and its impact on users; and finally, it presents what we think are important issues in close-range photogrammetry today.

Figure 1 : Close-range photogrammetric surveys.

2. From the middle of XIXth century to the 1990's: moderate recourse to vintage close-range photogrammetry

Photogrammetry was invented by Aimé Laussedat, a French military engineer in the middle of the XIXth century, in order to survey fortifications with terrestrial images (Laussedat, 1899). The first acquisition was carried out with a lucida camera, subsequent projects were done with photographs (Figure 2).

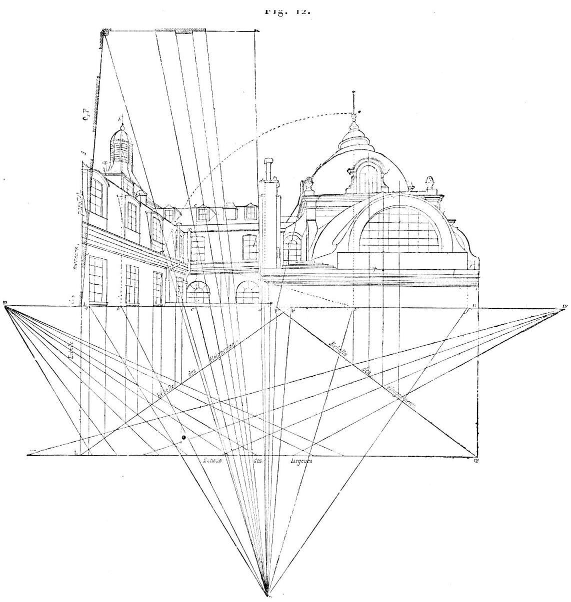

Figure 2 : View from the office of Laussedat, 1850.

2.1. Application to cultural heritage

Up to World War II, close-range photogrammetry was only sporadically used in France, mainly for architectural heritage documentation, much less than in Germany for instance, where Albrecht Meydenbauer had established systematic photogrammetric architectural surveys (Meydenbauer, 1896; Carbonnell, 1969). One of the instigators of the photogrammetric technology for heritage conservation in France was Henri Deneux (Deneux, 1930), chief architect of the cathedral of Reims, who developed his own methodology of geometric reconstruction by graphical drawing (Figure 3).

Just after its creation in 1940, IGN France, the French Mapping Agency (Institut Géographique National) was commissioned to study the potential of photogrammetry for cultural heritage preservation (IGN, 1948). The study was carried out by Georges Poivilliers, the creator of the French photogrammetric industry. During the winter 1944, he conducted some first tests in the Sainte Chapelle in Paris, the results of which were presented at the international congress of photogrammetry in The Hague (Figure 4).
Then IGN started to be quite active in close-range photogrammetry for architectural heritage documentation, with projects in France (Strasbourg, Saint-Denis, Amiens, Paris cathedrals, Panthéon and many other historical buildings) and around the world (Abu Simbel and the flooded temples in High Egypt, Borobodur temple in Indonesia, Royal Palace of Kathmandu in Nepal, pagodas of Pagan –Figure 5–, Acropolis of Athens, tower of Pisa etc.). At that time, maps, cross-sections and elevations were produced through totally manual stereo plotting on analog devices.

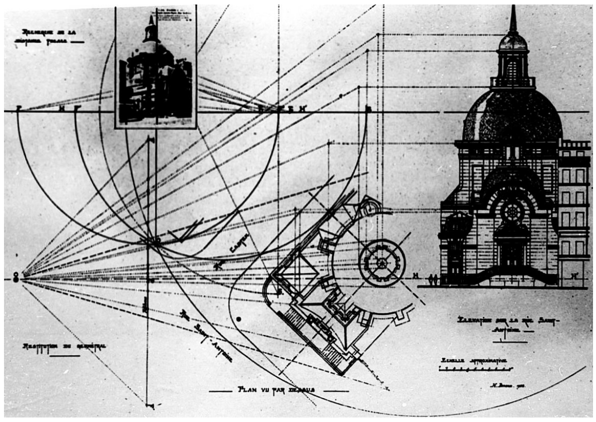

Figure 3 : Survey of Sainte Marie temple by Deneux.

It is worth mentioning that Maurice Carbonnell, as the manager of the Photogrammetry Department and head of the Center for Architectural and Archaeological Photogrammetry, was strongly involved in the creation of CIPA (International Committee for Documentation of Cultural Heritage) in 1968, which is still active internationally today.

There was another Photogrammetry department within the Ministry of Culture, to fulfill the ambitious plans of organizing a systematic national inventory, initiated in the 1960's by André Malraux (Figure 6).

In the 1990's, European directives pushed the public agencies to get rid of all activities which could compete with private business. From then on, apart from schools and research laboratories, more and more private companies, such as firms of chartered surveyors, have been engaged in documenting cultural heritage using close-range photogrammetry in France.

2.2. Engineering applications

From 1890 to 1935, terrestrial photogrammetry was also intensively used to survey the Alps mountains following Henri Vallot's and Paul Helbronner's initiative ("*les topographes alpinistes*") (Guilhot, 2006).
Since 1960, thanks to the development and the power of the first computers, it started to be possible to analytically solve the photogrammetric equations, giving an accuracy compatible with engineering applications, such as control of large mechanical assembly (in aeronautical,

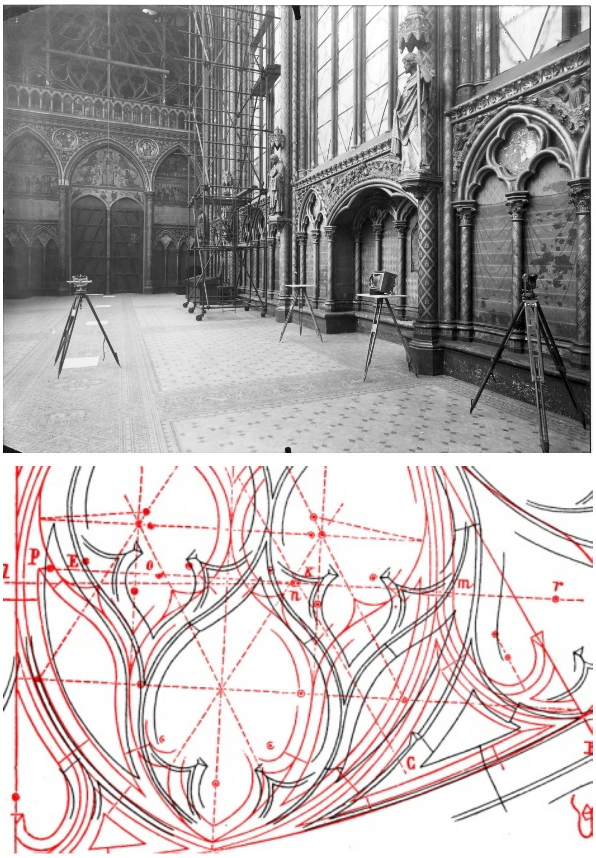

Figure 4 : Drawing of Viollet-le-Duc (red) versus photogrammetry (black). Sainte Chapelle, Paris, France.

Figure 5 : Htilominlo pagoda in Pagan (Burma).

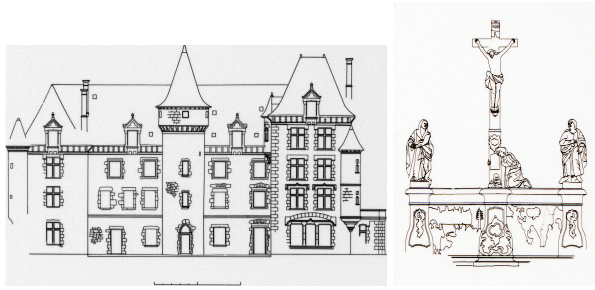

Figure 6 : Results of the Ministry of Culture in the 80's. Left: Posteils castle. Right: Geipolsheim calvary.

spatial, nuclear and car industry), stability test of bridges, tunnels, high buildings, and medical applications. At the same time, the development of graphical applications stimulated the use of aerial or terrestrial photogrammetry to produce the first 3D models of cities (Egels, 1989) as tools for urban management (see Figure 7).

Figure 7 : Photogrammetric 3D model of Mont-Saint-Michel (TRAPU database).

3. Laser scanner emergence

3.1. Terrestrial laser scanners

In the early 2000's, several manufacturers put terrestrial laser scanners on the market. Those instruments, expensive but fast, could measure thousands of points per second, notably to compute any cross-section instantaneously (Figure 8).

Some people thought for a while that surveying had become fully automatic! A lot of money was spent on scanning many heritage sites. But proper data processing was often neglected and thus under-budgeted. As a matter of fact, laser scanners provided the users with millions of 3D points, which were difficult to manipulate in most softwares. Besides, data processing, such as blunder elimination, point filtering, meshing and texturing, remained to be done manually, at least in part. Thus, people who invested most of their budget in data acquisition were a little frustrated. The need to precisely define the final user's requirements was loudly

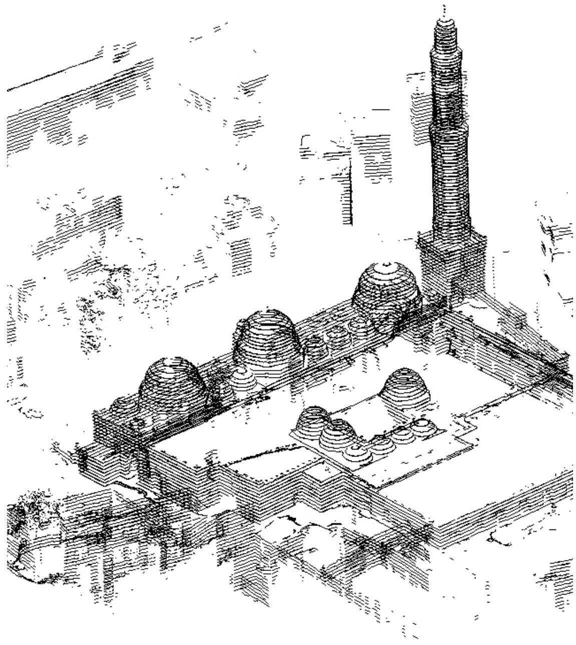

Figure 8 : Automatically computed cross-sections in laser 3D points of the mosque Al Muzzafar in Taez (Yemen).

expressed at that time, as it used to be the case in the 1960's, when comprehensive surveys that could be used for any application, were recommended (Carbonnell, 1969).

Once users were aware of the work involved in laser scanning, they started using it so efficiently that they could compete with image based procedure. Furthermore, the manufacturers quickly and significantly improved the capability of the scanning devices. From that time on, whatever the application, 3D data models were required next to the traditional products, such as maps and cross-sections.

Schools like the ENSG (Ecole Nationale des Sciences Géographiques) or the INSA Strasbourg (Institut National de Sciences Appliquées), which make their students practice close-range photogrammetry through real-size surveying projects, quickly added laser scanning to their traditional techniques. Research laboratories, like the MATIS lab in IGN, also adopted laser scanning techniques, at least to have reliable benchmarks for the assessment of image-based results. But the intensive use of laser scanning methods by private companies in heritage and industrial applications has not replaced the image-based methods or tacheometric surveys. In many heritage applications, attention must be paid not only to the shape that laser scanners can render reliably, but also to the aspect (drawings, colors), that image-based methods are more efficient to provide. In fact, both technologies can be complementary, scanners providing the shape, and images the aspect (Figure 9).

Figure 9 : Simultaneous use of laser and images to produce orthophotos of a cupola (orthogonal and azimuth projection).

3.2. 3D Mobile mapping

While users in various domains were investigating the high potential of static terrestrial laser scanners, some research laboratories were designing sophisticated vehicles for rapid 3D urban mapping, equipped with many sensors among which cameras and laser scanners. Examples comprise the Stereopolis vehicle of the MATIS lab of IGN France (Paparoditis, 2007; IGN, 2012), SIRADEL's mobile mapping system (Bénitez et al., 2010) and Lara3D at the CAOR laboratory of the Ecole des Mines ParisTech.

4. New developments

4.1. Image-based methods to produce 3D point clouds

In the mid-2000's, with the convergence of powerful computers, cloud computing and efficient algorithms for tie point matching, such as Scale-Invariant Feature Transform - SIFT (Lowe, 2004) and dense matching, e.g. SGM - Semi-Global Matching (Hirschmüller, 2008), new image-based methods were developed, able to automatically produce dense 3D point clouds, with realistic and precise colors, impossible to obtain with laser scanners (Figure 10). It is at present too soon, however, to say whether those new image-based methods to produce impressive 3D point clouds are going to compete with or complement laser techniques.

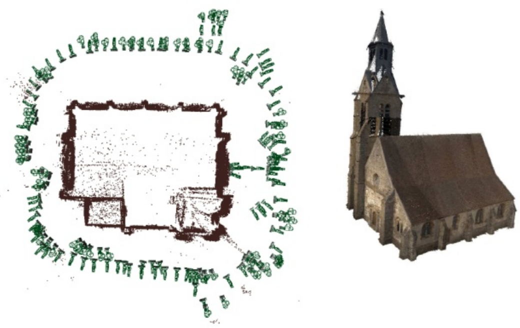

Figure 10 : 3D model on the Rampillon church near Paris produced by Micmac (the left image shows the camera positions).

Open source and free software appeared little by little on the web, such as "Micmac", a multi-resolution and optimization-based image matching software designed at IGN France (Pierrot-Deseilligny and Paparoditis, 2006), or PMVS (Furukawa and Ponce, 2010; PMVS, 2012). Automatic tools to register the images were also produced, like Bundler (Snavely et al., 2006), and Apero (Pierrot-Deseilligny and Clery, 2011). These fully automatic programs, running on standard computers, have lately started to reach new communities of users such as architects, archaeologists and geologists, who used to be reluctant to employ photogrammetry for their work, because of the high level of skills required combined with the dissuasive price of the equipment.
Application-dependent web servers which manage the whole process (image registration, dense matching, rendering) are now starting to be available. Such servers are meant to free the final user of any logistic constraint (no need to have a fast computer or install software at home).

4.2. Low cost aerial platforms

The development of affordable and efficient photogrammetric tools has pushed the quest for small and light aerial platforms to carry out inexpensive surveys such as small aircrafts and drones, equipped with a low-cost camera, controlled by a laptop computer. Private companies like "*L'Avion Jaune*" propose such services for any close-range application while the French Ministry of Ecology, Sustainable Development, and Energy is managing a project aimed at defining methods of 3D surveying by photogrammetric techniques based on images taken from unmanned aerial vehicles (UAV) (*Les drones, sentinelles de l'environnement*) (Figure 11).

Figure 11 : UAV drone ready for a test photo survey.

5. Today's issues and challenges of photogrammetry

5.1. Reconstruction

However attractive these new tools may be, important work remains to be done after the 3D point cloud computation, as some users are not only interested in point clouds, but also need semantic models, often to be provided in vector format. Deriving such information automatically from images and 3D point clouds is the domain of photogrammetric image analysis, sometimes called photogrammetric computer vision. This domain is still very much research-dominated and will not be covered in any degree of depth in this article. An example of ongoing activities is the recent work of the MATIS lab, e.g. (Burochin, 2012). Also a geometrically precise and topologically consistent photo-realistic rendering of the data is still a major research challenge, as many images need to be properly mosaicked to create a seamless visualization (Vallet and Houzay, 2011).

5.2. Real-time computation

The applications of close-range photogrammetry requiring real time computation used to have more of a "computer vision" flavor. Visual SLAM (simultaneous localization and mapping) for instance is a technique used by robots and autonomous vehicles to generate a map of an unknown environment while at the same time keeping track of the current location. Automatic urban vehicles are being investigated for a while, by the LASMEA research laboratory (Lasmea, 2012) for instance. The vehicles can be localized with kinematic GPS sensors wherever possible and with laser scanners and image-based solutions indoors or in case of GPS outage.
Traditional photogrammetry does not require that much real-time computation. However, new image-based methods to produce 3D point clouds, or mobile mapping applications, generate so much data that it is worth thinking about "real time": the objective is to completely process all data acquired during a day in the following night.

5.3. Efficiency and data management

Producing high-resolution 3D point clouds in a fully automated way is still an issue today. Even if image-based methods to produce 3D point clouds automatically have come a long way, most experiments are being carried out in relatively small projects. In order to manage bigger projects, dealing in some cases with thousands of terrestrial and aerial images, additional considerations like algorithmic complexity and efficiency, parallelization of code, appropriate computer hardware, GPU (Graphics Processing Unit) computing, cloud computing, and the addition of a database management system have to be seriously taken into account. Besides, beyond being able to obtain the result itself, the aspects of quality control and self-diagnosis need to be investigated in more details. In the past these aspects were often neglected, however they need to find a solution before the new techniques will find their way in to practical applications.

5.4. Web photogrammetry and crowd sourcing

Photogrammetric crowdsourcing refers to generating 3D information using informal social networks and web

2.0 technology (Heipke, 2010). Key differences to traditional photogrammetric data capture are the fact that often users lacking formal training in photogrammetry create the data themselves rather than relying on professional services; that potentially very large user groups collaborate voluntarily, and, often, without financial compensation with the result that at a very low monetary cost open datasets become available, and, that data capture and change detection potentially occur in real-time. Geospatial examples of crowd sourcing or VGI (volunteered geographic information, (Goodchild, 2007)) as it is sometimes called, comprise the creation of the OpenStreetMap data set and the road update process using the GPS tracks of the drivers as information source. This situation is similar to developments in the Open Source software environment. In close-range photogrammetry, the principles of crowd sourcing started to appear as e-learning tools for web photogrammetry (Grussenmeyer and Drap, 2000; Hohle, 2008). The early versions provided a user interface to upload images and have them oriented on the server. Photosynth (2012), a close range package developed around the open source software Bundler (Snavely et al., 2006) follows a similar path, yet on a more professional basis.

Such web-services (see also Section 4.1) are increasingly popular among the computer vision and the photogrammetry community. What is still missing, however, is a tool for interactive or semi-automatic capture of 3D photogrammetric data to create 3D city models from these images. It is expected that such services will emerge in the near future, since there already exist many web sites, where users have uploaded an enormous amount of digital images (the well known site Flickr being just one of them), awaiting exploitation in 3D.

In the cultural heritage field, the development of such tools to produce metric measurement archives is also expected to encourage the surveying of more sites, which would have been neglected previously.

5.5. Data rationalization

Since most acquisition techniques are close to being operational, more and more data are being acquired, at a higher and higher resolution. This tremendously huge amount of data needs to be rationalized for sustainability reasons. The objective is to offer anyone the possibility of visualizing, requesting or updating the existing data anytime. Data capture standards must be strictly followed by all data producers to reach this vital though ambitious objective. As far as heritage management is concerned for instance, the French Ministry of Culture and Communications is setting up a web platform (3D monuments, 2012), where any company surveying a heritage site can upload data. On the one hand, this avoids redundant acquisitions, and on the other hand, stimulates the need for more 3D models. Adopting general standards is a necessary prerequisite to the success of this platform.

6. Training

Despite the seeming simplicity of the new automatic tools, photogrammetric skills are still needed, as soon as tricky photo configurations occur. Photogrammetry courses in France are mostly offered at engineering schools such as the ENSG, INSA Strasbourg and the ESGT (Ecole Supérieure des Géomètres Topographes). At the ENSG, students are taught theoretical courses in photogrammetry. Some of them also take part in real-size close-range photogrammetric field surveys, which make them practice every phase in the design, acquisition and processing of georeferenced data, within the stimulating context of a real project. The ENSG has also been involved in a cooperation project with Yemen. In 2004, the ENSG surveyed the great mosque of Sana'a, on the point of being restored, in order to convince the Yemeni authorities of the advantages of close-range photogrammetry for the documentation of cultural heritage sites. Besides proving to Yemeni authorities the validity of photogrammetric techniques, the it was also intended to set up a specific Yemeni unit specialized in advanced documentation techniques to preserve the historical architectural heritage of Yemen (Heno and Egels, 2007). After many training sessions in Yemen, in France and through the web, the Yemeni team is now autonomous and up and running (Figure 12).

At INSA Strasbourg, a training program of 8 ECTS credits (2 of them dedicated to terrestrial photogrammetry) is proposed to students of the Civil Engineering and Surveying Department. Theoretical and practical aspects are developed in relation with the "Photogrammetry and Geomatics Group", namely for projects in cultural heritage documentation (Grussenmeyer and Guillemin, 2011; Grussenmeyer et al., 2011). The INSA interdisciplinary projects are linked to operational aspects of image-based approaches and laser scanning, by taking into account the user's needs in different research fields such as archaeology, architecture, geography and geology. In the past 15 years, the group has been involved in several projects in the Mediterranean countries. Current interdisciplinary projects are focused on antique architecture, medieval castles and fortresses, and environmental ecology by the study of entropic underground ecosystems. Since 2012, INSA has been involved in the training of architects from Palestine in heritage photogrammetry in the frame of the Maqdisi Program of the French Foreign Office. INSA and SFPT (French Society of Photogrammetry and Remote Sensing) will co-organize the XXIVth CIPA Symposium in Strasbourg from the 2nd to 6th September 2013.

In addition to these regular courses, specific workshops and web forums certainly help photogrammetry to become more accessible to non-specialists. The ENSG, for instance, set up a one week summer workshop on its premises in the south of France in August 2011, to present available photogrammetric tools to architects and archaeologists, who need to produce metric documents

Figure 12 : Orthoimage of the mosque Al Muzzafar in Taez (Yemen).

(Ecole d'été ENSG, 2011). The EDYTEM research laboratory in Le Bourget du Lac organized a similar workshop in June 2011 focused on natural environments (Ecole d'été Edytem, 2011). Both events were fully booked out, showing the growing interest of communities outside geomatics in photogrammetry. It is interesting to recall that recommendations to increase the links between the photogrammetrists and potential users of that technique such as architects or archaeologists, have been regularly repeated for at least 50 years by professional associations such as the SFPT (Roussilhe, 1936).

7. Conclusions

For more than a century, close-range photogrammetry was used as a reliable geometric measurement tool, for describing buildings and monuments from terrestrial photographs. It was first only used by companies which were able to invest relatively large amounts of money in hardware and skilled staff. Highly specialized hardware was indeed required for the photogrammetric survey as well as for stereo plotting, which used to be a strictly manual task.

Recent technological progress and a general hype for 3D products have significantly improved the economical perspectives of this technique. It is indeed no longer reserved to a few specifically trained technicians, but is on the contrary conquering new jobs, (see RFPT issue 196, (Heno, 2010, 2011)). However, photogrammetry remains complex: its democratization needs the technical and pedagogical help from properly trained photogrammetrists.

Today, close-range photogrammetry (or 3D optical measurement techniques, as it is sometimes called) has widespread applications much beyond architecture, archaeology and cultural heritage preservation. It is also increasingly being used in different engineering sectors, e. g. for improving car safety in the automobile industry (Raguse and Heipke, 2009), as well as in geology, medicine, sports and in the film industry. The latter also provides a link to virtual and augmented reality and to computer graphics. Also, besides single images, image sequences and video streams are increasingly being processed using the same photogrammetric principles. In this way not only static scenes can be surveyed, but also dynamic processes are being captured, and photogrammetry can also be employed for tasks such as traffic monitoring and security surveillance.

These new developments have become possible due to significant progress in sensor technology, automation and, perhaps above all due to the fact that today virtually everybody can capture digital images using inexpensive cameras or mobile phones. They are proof of a very vital and fascinating discipline with lots of potential for future growth and applications.

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